TRANSLINEAR AMPLIFIER

RELATED PATENT APPLICATION

This application is related to US patent application

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and assigned to the same assignee as the present invention.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The invention relates to integrated MOSFET semiconductor circuits, and more in

particular to a translinear amplifier. According to the objectives of the invention said

translinear amplifier is intended to work linearly within a wide specified region and to

achieve sharp cutoff edges at the limits of said linear operating region, to force e.g. a switching transistor, which said translinear amplifier may be intended to drive, into minimum RDSon or maximum RDSoff. A possible, but not exclusive, use is to control a chain of switching transistors for a voltage controlled capacitor, formed by a larger number of small capacitors.

(2) Description of the Prior Art

In a translinear amplifier, the output voltage difference is kept at the same relative difference as the input voltage difference, independent of the absolute output voltage level. Said translinear amplifier is normally formed by two current balancing circuits and some form of an amplifier stage, where the amplifier forces the output voltage difference to be exactly the input voltage difference.

Fig. 1(Prior Art) shows the block presentation of a translinear amplifier and **Fig 2 (Prior Art)** shows the principal components diagram of a translinear amplifier

In **Fig. 2 (Prior Art)** a first current dividing circuit with two branches, **N1** and **N2**, and with a common current source **I1**, is connected to said translinear amplifier's inputs **Vin-p** and **Vin-n**. ; A second current dividing circuit with two branches, **N5** and **N6**, and with a common current source **I2** is connected with said translinear amplifier's reference voltage **Vr f** and with said translinear amplifier's output **Vout**. In both current-dividing

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circuits, a current probing circuit (**N4** and **N8**) determines the current in one of its branches, which is a measure of the current ratio within each said current dividing circuit. An amplifier **AMP** compares both current probing signals and, in a closed feedback loop, forces the output voltage **Vout** to change until both values measured at said current probes are the same. The amplifier AMP generates **Vout-p** such **that I2p = I1p**, which is only true if **Vin-p – Vin-n = Vout-p – Vout-n**. The absolute voltage level of **Vout p** and **Vout n** is independent of the level of **Vin-p** and **Vin-n**. As can be seen, the translinear amplifier works as a perfect level shifter with a gain of 1. The translinear amplifier operates linear in a wide voltage range, however the characteristic is more or less undefined outside this normal operating range, causing soft cutoff edges at the limits of said linear operating region.

U.S. Patent 6,121,824 (to Opris) describes a translinear circuit with series resistance compensation, where a sub circuit including three bipolar transistors is substituted in place of a single bipolar transistor to achieve extrinsic base and emitter series resistance compensation in translinear circuits.

U.S. Patent 5,432,474 (to Lauffenburger and Moore) discloses a fixed and adjustable bandwidth translinear input amplifier. An improved method and circuitry for processing high-impedance (current mode) input signals for use in translinear and other mode circuits in a manner that avoids the signal dependent bandwidth variations that

occur in the prior art. A non-linear feedback structure using a transconductance gain element is employed to extend the bandwidth and/or suppress bandwidth variations.

SUMMARY OF THE INVENTION

In accordance with the objectives of this invention, in a first aspect, a simplified translinear amplifier, working linear within a wide specified region, is achieved and, in a second aspect, added functions to achieve sharp cutoff edges at the limits of said linear operating region.   A possible, but not exclusive, application is a voltage controlled capacitor, formed by a larger number of small capacitors and controlled through a chain of switching transistors, where each transistor within said chain of switching transistors is driven by one translinear amplifier.

According to said first aspect, the amplifier portion within the circuit is implemented with the smallest possible circuit count and is finally degraded to just a diode connection.

The translinear amplifier, as used in this invention, uses a first current dividing circuit with two branches, with at least one MOSFET transistor in each branch, and with

a common current source, where the gates of said MOSFET transistors are connected with the translinear amplifier's inputs and where the current ratio in said branches of said first current dividing circuit is dependent on said translinear amplifier's input voltage difference, and it uses a second current dividing circuit with two branches, with at least one MOSFET transistor in each branch, and with a common current source, where one gate of said MOSFET transistors is connected with said translinear amplifier's reference voltage and the other gate is connected to said translinear amplifier's output and where the current ratio in said branches of said second current dividing circuit is dependent on the voltage difference of said translinear amplifier's reference voltage and output voltage; and it implements a closed feedback loop to force the current division within said first current dividing circuit and the current division within said second current dividing circuit to the same value of current ratios.

According to the invention, a novel form of closed feedback loop within said translinear amplifier is implemented. Said closed feedback loop measures the current with a current probing device in one branch of said first current dividing circuit and feeds the measured value to a current controlling device placed in the equivalent position of one branch of said second current dividing circuit. As a consequence said second current dividing circuit is forced out of balance, which then forces, due to the closed feedback loop, said second current dividing circuit to react, until said input voltage difference and said difference of the voltages between said translinear amplifier's reference voltage and output voltage are the same.

According to the invention, a possible solution for device providing the required reaction is just one MOSFET transistor, used as a diode, i.e. with the source and the gate of said MOSFET transistor directly connected. That MOSFET transistor would replace the current probing device of the prior art solution. In addition part of the closed feedback loop is realized by means of a simple connection between the source and the gate of said MOSFET transistors connected to say translinear amplifier's output. As can be seen, the components normally required for an amplifier within the feedback loop are completely eliminated.

The translinear amplifier normally has a gain of 1. Said gain can also be different from 1; however for a gain different from 1, the translinear amplifier is only linear for small signals.

According to said second aspect, two additional circuit functions sharply limit the analog operating region through an extra current limiting transistor on one side and the purposely use of the voltage limited by the power supply on the other side. A possible application in mind is to linearly control said translinear amplifier's output, for example for switching on or off a transistor in an application where a wide linear range is desired, and getting sharp cutoff edges, for example for switching on or off a transistor in said application to achieve minimum RDSon and maximum of RDSoff at the extreme ends.

A second fundamental concept in accordance with the objectives of the invention for the translinear amplifier, to work linearly within a wide specified voltage range and then having sharp cutoff edges at the limits of said linear operating range is to add

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circuits to, first, define the linear operating range and then, second, to sharply raise said translinear amplifier's (negative) output voltage, outside the linear operating range, as well as to sharply limit said translinear amplifier's (positive) output voltage outside the linear operating range. A limiting transistor circuit builds the circuit to sharply drive the output to negative voltage, once the linear range is exceeded on one side. To get a sharp limit of the output voltage on the opposite side, the limiting function of the supply voltage is used as a purposely effect. No additional components are required to achieve the desired effect in this case.

An even further concept implemented in the proposed circuit is to switch off most of the circuit elements to reduce the power consumption when the translinear amplifier itself is outside said linear operating range.

In accordance with the objectives of this invention, in said first aspect, a simplified translinear amplifier, working linear within a wide specified region, is achieved and, in said second aspect, added functions to provide sharp cutoff edges at the limits of said linear operating region, are achieved.

According to the objectives of the invention, the following methods are applied. Whenever the differential input voltage changes, the current balance ratio in the first current balancing circuit changes accordingly. A current probing device within the current path of said first current balancing circuit generates a signal, representing the actual current in that path. A connection feeds said current probing signal to the gate of a current controlling device within the current path of said second current balancing

circuit, which is placed at the same position as said current probing device in said first current balancing circuit. Said current controlling device, by means of said current controlling signal, forces said second current balancing circuit out of balance, which, as a direct consequence, forces said second current balancing circuit to react, until said second current balancing circuit reaches a new stable current ratio, which is now the same ratio as in said first current balancing circuit. Now the voltage difference between said translinear amplifier's output voltage Vout and the reference voltage Vref is the same as the differential input voltage between Vin-p and Vin-n of said translinear amplifier.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, forming a material part of this description, there is shown:

Fig. 1 (Prior Art) shows block presentation of a translinear amplifier.

Fig. 2 (Prior Art) shows a principal components diagram of a possible solution of a translinear amplifier.

Fig. 3 shows a principal components diagram of a translinear amplifier with an amplifier stage with minimal component count.

Fig. 4 demonstrates a translinear amplifier driving a P-MOS switcher in a varicap application

Fig. 5 visualizes the relationship of the input differential voltage and the output differential voltage of the translinear amplifier.

Fig. 6 shows a more detailed schematic of a possible final circuit solution.

Fig. 7 shows the circuit with the additional limiting transistor function.

Fig. 8 shows the circuit with the additional power saving function.

Fig. 9 shows a principal concept circuit for a reference voltage generation, compensating the temperature characteristics of the P-MOS switcher.

Fig. 10 briefly demonstrates the methods applied within the translinear amplifier.

Fig. 11 briefly demonstrates the methods to sharply cut off the linear opreating range.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The objectives of this invention are to build an amplifier, which keeps the output voltage difference at the same relative difference as the input voltage difference to said amplifier within a wide and well-defined linear range. Further the objectives are to sharply limit the analog operating region and to change to a typical switching characteristic when the output signal leaves said defined linear range. A possible application in mind is linearly switching on or off a transistor, and getting sharp maxima and minima of its RDS at the extreme ends. That linear switching function could be used in a switching chain for a voltage controlled variable capacitor, made of a larger number of small capacitors. The proposed invention can provide the controlling mechanism for such voltage controlled variable capacitor with excellent linearity and high Q for the use in oscillators and variable filters.

In a first aspect, a simplified translinear amplifier, working linear within a wide specified region, is achieved and, in a second aspect, functions are added to achieve sharp cutoff edges at the limits of said linear operating region.

According to said first aspect, the amplifier stage AMP in **Fig. 2 (Prior Art)** is implemented with the smallest possible circuit count. Said amplifier stage AMP is finally degraded to just a diode connection, as is shown in **Fig. 3**.

In the circuit of **Fig. 2 (Prior Art)**, a voltage difference **Vdiff-in = Vin-p – Vin-n** divides the current **I1** into **I1p** and **I1n**. The amplifier **AMP** in **Fig. 2** takes the voltages

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at the gates of the current probing transistors **N4** and **N8** and changes the voltage at the gate of **N6** until said voltages at said gates of transistors **N4** and **N8** are equal, i.e. said amplifier generates **Vout-p** such that **I2p = I1p**, which is only true if **Vin-p − Vin-n = Vout-p − Vout-n**.

The translinear amplifier, as used in this invention and shown in **Fig. 3**, uses a first current dividing circuit with two branches, built by MOSFET transistors **N1-3** and **N2-3**, and with a common current source **I1-3**, and connecting to said translinear amplifier's inputs **Vin-p-3** and **Vin-n-3**, And it uses a second current dividing circuit with two branches, built by MOSFET transistors **N5-3** and **N6-3**, and with a common current source **I2-3**, connecting to said translinear amplifier's reference voltage **Vref = Vout-n-3** and to said translinear amplifier's output **Vout = Vout-p-3**.

According to the invention, a novel form of closed feedback loop within said translinear amplifier is implemented to force the current division within said first current dividing circuit and the current division within said second current dividing circuit to the same value of current ratios. Said closed feedback loop measures the current with a current probing device **N4-3** in one branch of said first current dividing circuit and feeds the measured value to a current controlling device **N8-3** placed in the equivalent position of one branch of said second current dividing circuit. As a consequence, when the current in said first current dividing circuit changes, said second current dividing circuit is forced out of balance by said current controlling device. Then it forces said second current dividing circuit to react, until said input voltage difference **Vdiff-in = Vin-p-3 − Vin-n-3** and said difference of the voltages between said translinear amplifier's

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reference voltage and output voltage **Vdiff-out = V ut-p-3 – Vout-n-3** are the same.

MOSFET transistor **N6-3** plays a major role in that feedback loop: said transistor has its

gate directly connected to the drain of **N6-3** and therefore the gate voltage follows

directly the voltage of the connected drains of **N6-3** and **N8-3**. In the proposed solution,

MOSFET transistor **N6-3** can also be considered to work as a diode

MOSFET transistor **N8-3** would replace the current probing device **N8-2** of the

prior art solution. In addition part of the closed feedback loop is realized by means of a

simple connection between the source and the gate of said MOSFET transistor **N6-3**

connected to said translinear amplifier's output. As can be seen, the normally required

components of an amplifier **AMP** of prior art within the feedback loop are completely

eliminated: the former amplifier **AMP** is now degraded to a simple diode connection.

The circuit operation operates as its best when the output load at **Vout-p-3** is of

high impedance, as it is the case in the proposed application for a capacitor switching

chain for a voltage controlled variable capacitor with linear characteristic. One such

stage of said capacitor switching chain is shown in **Fig. 4**.

The translinear amplifier normally has a gain of 1. Said gain can also be different

from 1; however for a gain different from 1, the translinear amplifier is only linear for

small signals.

The gain of a translinear amplifier is $\sqrt{\dfrac{I2}{I1} * \dfrac{W2/L2}{W1/L1}}$.

According to said second aspect, two additional circuit functions sharply limit the analog operating region through an extra current limiting transistor on one side and the purposely use of the voltage limited by the power supply on the other side. Key objective is to linearly control said translinear amplifier's output, for example for switching on or off a transistor in an application like it is shown in **Fig. 4**, and getting sharp cutoff edges, for example for switching on or off a transistor in said application to achieve minimum RDSon and maximum of RDSoff at the extreme ends. The desired output characteristic is visualized in **Fig. 5**.

Fig. 5 visualizes the relation between the input voltages **Vin-p/ Vin-n** and the output voltages **Vout-p / Vout-n**. The differential input voltage **Vin-diff**, represented by lines **51** and **52** is mirrored at lines **50a** and **50b** into the output differential voltage **Vout-diff**, represented by lines **53** and **54**. The translinear operation of the translinear amplifier, is visualized with lines **55** and **56**, where lines **51**, **50a** and **55** always cross at the same point and where also lines **52**, **50a** and **56** always cross at the same point; said lines **55** and **56** together, representing said translinear operation of said translinear amplifier, may have varying angles, but are forced to be always in parallel. Said lines **51** and **52**, representing said differential input voltage **Vin-diff**, can slide together, with constant distance, up and down the input voltage scale, then their crossing points with lines **55** and **56** also slide along line **50a**. Similar, said lines **53** and **54**, representing

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said differential output voltage **Vout-diff**, can slide together up and down the output

voltage scale and their crossing points with lines **55** and **56** then slide along line **50b**.

When said input voltages, represented by lines **51** and **52**, have a specific

differential value, i.e. lines **51** and **52** have a specific distance, the mirroring mechanism

of said translinear amplifier, represented by said lines **55** and **56**, forces said lines **53**

and **54** to be at that same distance, i.e. said output voltage, represented by lines **53** and

54, takes the identical differential value **Vout-diff**, as the differential input voltage **Vin-diff**. As soon as said differential input voltage **Vin-diff** changes, said differential output

voltage **Vout-diff** is forced to change by the same amount, independent of their

absolute position on the voltage scale.

The linear operating region on line **50b** is marked as the area **59** in **Fig. 5**. Once

either output **Vout-p** or **Vout-n** reaches the cut-off voltage **Vlim** or when it reaches the

power supply line **Vdd**, the linear operation is sharply cut off.

A more detailed schematic of a possible final circuit solution is shown in **Fig. 6**.

Equivalent to **Fig. 3**, a first current dividing circuit is built of two branches, with

transistors **N1-6** and **N2-6**, and a common current source **I1-6** with transistor **N11-6**;

said first current dividing circuit connects to said translinear amplifier's inputs **Vin-p-6**

and **Vin-n-6**. Further, a second current dividing circuit is built of two branches, with

transistors **N5-6** and **N6-6**, and a common current source **I2-6** with transistor **N12-6**;

said first current dividing circuit connects to said translinear amplifier's reference voltage

Vout-n-6 = Vref and to said translinear amplifier's output **Vout-p-6 = V ut**. Transistor

N10-6 produces a common voltage, controlled by **Ibias** to control said current sources **I1-6** and **I2-6**.

According to the invention, said novel form of closed feedback loop within said translinear amplifier to force the current division within said first current dividing circuit and the current division within said second current dividing circuit to the same value of current ratios uses said current probing device **(N4-6)** within said first current dividing circuit and feeds the measured value to a current controlling device **(N8-6)** placed in the equivalent position within said second current dividing circuit. As demonstrated with **Fig. 3,** transistor **N6-6** plays a major role in that feedback loop: said transistor has its gate directly connected to the drain of **N6-6** and therefore the gate voltage follows directly the voltage of the connected drains of **N6-6** and **N8-6**. As it was already demonstrated in **Fig. 3**, in the proposed solution, MOSFET transistor **N6-6** operates as said amplifier AMP, degraded to a diode,

The transistors equivalent to **N3-3** and **N7-3** in **Fig. 3** are not implemented in said circuit of Fig.6: they were implemented for perfect symmetry, but they are not necessary.

All transistors in said circuit of **Fig. 6** are MOSFET transistor; all transistors could also be replaced together with their complementary equivalents:

Fig. 7 shows the circuit of **Fig. 6** with the additional limiting transistor function, where the additional components are shown inside the dashed frames, marked with **ADD-COMP 1-7** and **ADD-COMP 2-7**. According to said second aspect of this

invention, two additional circuit functions sharply limit the analog operating region

through an extra current limiting transistor on one side and the purposely use of the

voltage limited by the power supply on the other side. Transistor **N13-7** incorporates

said current limiting transistor. Transistor **N3-7** takes a current probe of said first current

dividing circuit, built by transistors **N1-7**, **N2-7** and **N4-7** and mirrors it through **N16-7** to

said current limiting transistor **N13-7**. As soon as the current drawn by **N13-7** exceeds

the current provided by **N8-7**, **N13-7** sinks all available current and the output is cut-off.

Similar, when the output voltage **Voutp-7** swings **Vdd**, further voltage increase is

suddenly impossible, this sharply limiting said linear operation region.

Fig. 8 shows the circuit of **Fig. 7** with the additional power saving function,

where the additional components are shown inside the dashed frames, marked with

ADD-COMP 1-8, **ADD-COMP 2-8** and **ADD-COMP 3-8**. One concept implemented in

the proposed circuit is to switch off most of the circuit elements to reduce the power

consumption when the translinear amplifier itself is outside said linear operating range.

Transistor **N19-8** and **N21-8** take a current probe on both branches of said first current

dividing circuit, built by transistors **N1-8**, **N2-8** and N4-and once the current in either

branch becomes very low, said second current dividing circuit, built by transistors **N5-8**,

N6-8 and **N8-8** is switched off as well by means of transistors **N17-8** and **N18-8**.

Fig. 9 shows the temperature compensating mechanism, implemented with the

reference voltage generating circuit. Transistor **N1-9** and current source **I1-9** generate

a reference voltage **Vref**, which then is connected to **Voutn-9** of the translinear

amplifier. Transistor **N2-9** is a P-MOS switch and its input gate **VG** is attached to the

output **Voutp-9** of said translinear amplifier, for example to drive one switching stage

within in a possible application of a voltage controlled capacitor, formed by a larger

number of small capacitors **CAP** and controlled through a chain of switching transistors.

Transistor **N1-9** is of the same P-MOS type as the P-MOS switch **N2-9** and therefore

has the same temperature characteristics as P-MOS switch **N2-9**. The proposed

arrangement of P-MOS transistor **N1-9** compensates the temperature error of P-MOS

switch **N2-9**.

Similar, when the transistor **N2-9** is a N-MOS type transistor, a N-MOS type

could also be used a within the reference voltage circuit.

A first fundamental concept of the disclosed invention is to add the methods and

mechanism to achieve, in a first aspect, a simplified translinear amplifier, working linear

within a wide specified region, and, in a second aspect, add functions to achieve sharp

cutoff edges at the limits of said linear operating region, see **Fig. 3**. A first current

dividing circuit with two branches, with **N1-3** and **N2-3**, and with a common current

source, **I1-3** connects to said translinear amplifier's inputs **Vinp-3** and **Vinn-3**. The

current ratio in said branches of said first current dividing circuit directly depends on

said translinear amplifier's input voltage difference; A second current dividing circuit

with two branches, with **N5-3** and **N6-3**, and with a common current source **I2-3**

connects with said translinear amplifier's reference voltage **Vr f = Voutn-3** and with

said translinear amplifier's output **Vout** = Voutp-3. Similar, the current ratio in said

branches of said second current dividing circuit directly depends on said translinear

amplifier's voltage difference between said reference voltage and said output voltage. A

closed feedback loop forces the current division within said first current dividing circuit

and the current division within said second current dividing circuit to the same value of

current ratios. Said closed feedback loop is primarily built of transistors **N4-3** and **N8-3**

and of the direct connection between drain and gate of transistor **N6-3**.

A second fundamental concept in accordance with the objectives of the invention

for the translinear amplifier, working linearly within a wide specified voltage range and

having sharp cutoff edges at the limits of said linear operating range is to add circuit

elements to define the linear operating range. Outside the linear operating range the

circuit according to this invention will sharply raise said translinear amplifier's (negative)

output voltage, or will sharply limit said translinear amplifier's (positive) output voltage.

Transistors **N13-7**, **N3-7**, **N14-7** and **N16-7** in the circuit of **Fig. 8** build the circuit to

sharply drive the ouput to negative voltage, once the linear range is exceeded.

To get a sharp limit of the output voltage, the limiting function of the supply voltage is

used as a purposely effect. No additional components are required to achieve the

desired effect.

In accordance with the objectives of this invention, in a first aspect, a simplified

translinear amplifier, working linear within a wide specified region, is achieved and, in a

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second aspect, added functions to provide sharp cutoff edges at the limits of said linear operating region, is achieved.

The first method to achieve the objectives of this invention is illustrated in **Fig. 10.** Whenever the differential input voltage changes **(101)**, the current balance ratio in the first current balancing circuit changes accordingly **(102)**. A transistor diode (N4-3) within the current path of said first current balancing circuit generates a voltage probe **(103)**, representing the actual current in that path. A connection feeds said current probing voltage to the gate of a transistor (N8-3) within the current path of said second current balancing circuit, and which is placed in the same position as is transistor (N4) in said first current balancing circuit. Said current probing voltage brings said second current balancing circuit out of balance **(104)**, which, as a direct consequence, said transistor (N8-3) forces the source of transistor (N6-3) to float and the gate of transistor (N6-3), which is directly connected to the same transistor's source floats with it, until said second current balancing circuit is in a new stable current ratio, which is now the same ratio as in said first current balancing circuit **(105)**. Now the voltage difference between Vout and Vref is the same as the differential input voltage of Vin-p and Vin-n **(106)**.

The second method to achieve the objectives of this invention is illustrated in **Fig. 11.** Whenever the differential input voltage changes or when the reference voltage for the output is changed, i.e. adjusted to a new value, **(111)** the output voltage VOUT start to change according to said differential input voltage change or to said output reference voltage change **(112)**. If said output voltage goes beyond the cut-off limit VLIM **(113)**,

Sharply cut off the output **(114)**. If said output voltage exceeds power supply Vdd **(115)**, sharply cut off the output **(116)**. However, if the output stays within the linear operating region, continue to change the output voltage VOUT according to differential input voltage change or to output reference voltage change **(117)**.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

What is claimed is: